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# Enhancing the Performance of Reinforced Concrete Beams Using Wrapping Technique

Research Paper

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## ABSTRACT

Old structures beyond their design age become critical in terms of structural integrity, and with limited serviceability they pose serious health and safety risks for the occupants. Rehabilitation and retrofitting of these structures is must to extend their serviceability and mitigation of risk to life due to structural failure. An attempt has been made to examine the performance of strengthened reinforced concrete (RC) beams in terms of its flexural strength. The effect of adding different layers of stainless-steel wire meshes (SSWM) to RC beams has also been investigated. For this, RC beams strengthened with various SSWM wrapping configurations have been subjected to a two-point flexural stress. In this study, a series of flexural strength tests were conducted on various combinations of wrappings (360°-Wrap and U-Wrap) and concrete (M20 and M60). These combinations have been compared in terms of different gain in flexural strength.

**Keywords:** *Stainless steel wire mesh, Fiber reinforced concrete, Epoxy, Flexural strength*

## INTRODUCTION

Effects of aging in structures are exhibited mainly in terms of concrete deterioration and steel corrosion. The deterioration occurs due to exposure to varying temperature, freeze-thaw cycles, contact with chemicals, salt water, and UV radiation. Apart from the above, natural hazards like recurring earthquakes, landslides, volcanic eruptions, cyclones, or tornados also contribute towards structural weakening. This repetitive cycle of exposure happens during the entire life span of all the structures (dwellings, power plants, industrial infrastructure, dams, and bridges).

Periodic monitoring of old structures, especially, for those surpassed their design life, is crucial. Special attention should also be given to civil structures or historic buildings in areas prone to natural hazards mentioned earlier. Negligence in such cases could lead to structural damage, loss of property and life endangerment for the occupants. There are number approaches available for mitigation of this risk such as demolition and reconstruction, rehabilitation, restoration and retrofitting/ strengthening.

Rehabilitation means returning an old structure to its useful state by means of repair, modification, or alteration considering the strength aspect. This includes filling wide cracks using suitable materials like epoxy, removal of damaged portion of the masonry and reconstructing it, addition of wire mesh on both sides of load bearing walls etc. (IRC-SP:40-2019; CPWD Handbook, 2002).

The term retrofitting is widely associated with strengthening of structures located in areas prone to natural hazards like earthquakes. It includes increasing lateral strength in one or both directions by adding reinforcements, increasing wall areas or increasing number of walls and columns, removal of sources of weakness or abrupt change in stiffness

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between consecutive stories, avoiding possibility of brittle mode of failure by proper reinforcement and connection between resisting members etc. (Gkournelo *et al.*, 2021).

Re-construction is simplest of them all, but not a cost-effective solution and can be opted in or opted out on case-by-case bases. Also, retrofitting, structural rehabilitation and strengthening are financially driven choices.

In the present study, PCC and RCC beams of M20 and M60 concrete have been strengthened with 360°-Wrap and U-Wrap techniques. Their performances have been compared in terms of flexural strength.

## MATERIALS AND METHODS

Properties of materials used in experimental investigation have been described in this section.

### Cement

53 grade Ordinary Portland Cement (OPC) with specific gravity of 3.15 has been used in the study.

### Natural Aggregates

Coarse and fine aggregates with specific gravities of 2.63 and 2.59 have been used in the study. Coarse aggregates of maximum nominal size of 20 mm as per the specifications IS-383:1970 was used in the study. Fine aggregates used in the study confirms to the grading zone II as per the specification of IS-383:1970.

### Stainless Steel Wire Mesh (SSWM)

Standard stainless steel wire mesh of mesh size 40 has been used in the study. The physical properties of the mesh have been reported in Table 1.

**Table 1.** Physical properties of SSWM

| **Properties (s)** | **Value (s)** |
|---|---|
| Woven Type | Square |
| Mesh per inch | 40 |
| Standard Wire Gauge | 32 |
| Diameter of Wire (mm) | 0.25 |
| Size of Opening (mm) | 0.365 |

### Bonding Materials

Araldite AW106 and Hardener HV953 have been mixed as per manufacturer's instructions to prepare a suitable bonding material. Their individual and combined properties have been reported in Table 2 below.

**Table 2.** Properties of Bonding Material

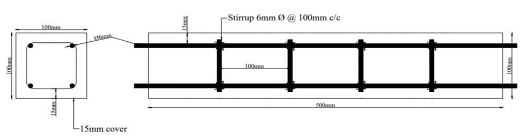
| Properties | Araldite AW106 | Hardener HV953 | Mix |
|---|---|---|---|
| Viscosity at 25°C (pas) | 30-50 | 20-35 | 30-45 |
| Specific Gravity | 1.15 | 0.95 | 1.05 |
| Colour (visual) | Neutral | Brownish Yellow | Pale Yellow |

### Reinforcement

The 6 mm diameter steel bars have been used as main reinforcements and stirrups for a 500 mm long, 100 mm wide and 100 mm thick beam.

### Control Beam

A 500 mm long, 100 mm wide and 100 mm thick beam with 15 mm cover, and 100 mm center to center spacing for reinforcement has been considered as a control beam (see Figure 1a). Figure 1b shows the mould and reinforcement used for casting the beams. The control beams and strengthened beams have been subjected to identical support and loading conditions to assess and compare the performances with different wrapping techniques.




a) Schematic view of reinforcement

b) Mould and reinforcement

**Fig. 1.** Details of reinforcement

### Strengthened Beam

The beams are strengthened using U-wrap and 360°-wrap techniques. In U-wrap, only 3 faces of the

beam are wrapped with stainless steel wire mesh (SSWM) and epoxy composite. In this scenario, load has been applied to the unwrapped face of the beam. In 360°-wrap, all sides of the beam are wrapped with SSWM and epoxy composite.

### Design Mix

The mix proportions for M20 and M60 grade concrete have been calculated as per the specifications of IS-10262:2019. The designed mix proportions and quantities calculated for M20 and M60 concrete have been reported in Table 3 below.

**Table 3.** Design Mix Proportions (quantities in kg/$m^3$)

| **Concrete Grade** | **M20** | | **M60** | |
|---|---|---|---|---|
| *Constituents* | *Mix proportion* | *Quantity* | *Mix proportion* | *Quantity* |
| *Cement* | 1 | 350 | 1 | 450 |
| *Fine Aggregate* | 1.9 | 694.94 | 1.455 | 570.21 |
| *Coarse Aggregate* | 3.5 | 1103.75 | 2.218 | 1087.36 |
| *Water* | 0.54 | 192 | 0.28 | 140.5 |

In M60 concrete, mineral admixture of 40 kg/m3 and chemical admixture of 2.45 kg/m3 was used.

## EXPERIMENTAL PLAN

### Casting of Control Beams

The homogenous mixing of constituents of the concrete mix is ensured by using a mechanized concrete mixer as shown in Figure 2.

**Fig. 2.** Mixing of Concrete

### Compaction

The concrete mix was poured into the mould and then compacted using a mechanical vibrator (see Figure 3). The surface was then finished off by levelling and smoothening using a trowel.

**Fig.3.** Compaction of Concrete Specimens

### Curing

Curing is one of the most important steps in sample preparation. It inhibits excess loss of water from the concrete specimen during the hydration process and prevents concrete from cracking under the strain of contraction before it gets fully hardened. Concrete specimens for various tests were cured in a rectangular tank as shown in Figure 4.

**Fig.4.** Curing of concrete specimen

### Preparation of Strengthened Beam Specimens

The surface of concrete beam specimen was scrubbed gently using a sandpaper and then cleaned with an air blower to eliminate any dirt and debris sticking to the surface. The epoxy resins were then mixed as per the manufacturer's instructions in a plastic container. The epoxy resin coating is spread on the beam specimen, and then the steel wire mesh

was wrapped. A roller is then used to push the resin through the mesh until all air bubbles were removed. A consistent, steady pressure was given to the surface of the composite wire mesh until the epoxy was cured; this helps to extrude any excess resin and creates a solid bond between the epoxy, the concrete, and the mesh. Stainless steel wire mesh is embedded into the concrete and allowed to cure for 24 hours at room temperature. Similar procedure was carried for both 360°-wrap and U-wrap type wrapping. A binding wire was used as an interlocking mechanism for a 360° wrapping. Some of the important imagery showing the above explained steps have been presented in Figure 5.

a) Mixing of Epoxy Resins

b) Spreading of Epoxy Mix on Beam Surface

c) Removing Air Bubbles using a Roller

d) Interlocking of Mesh with Binding wire

e) Finishing of Stregnthened Beams

**Fig.5.** Casting Process of a Strengthened Beam

## Setup

### *Compressive Strength*

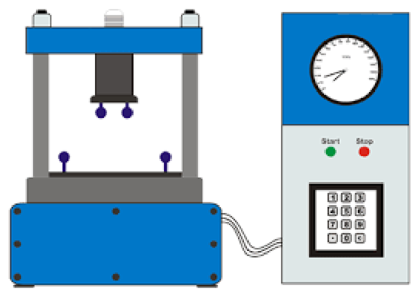
A series of compressive strength tests have been conducted on specimens of M20 and M60 grade concrete mixes for 7-days and 28-days compressive strength in a compression testing machine as per the specifications of IS-516:1959. The sample and analysis plan has been presented in Table 4.

**Table 4.** Sampling and Analysis Plan for Compressive Strength Test

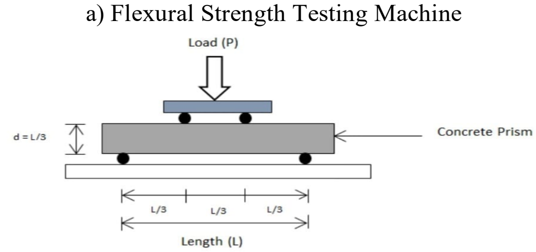
| Age of concrete | No. of cubes | |
|---|---|---|
| | **M20** | **M60** |
| 7-days | 3 | 3 |
| 28-days | 3 | 3 |

### *Flexural Strength*

After 28 days of curing, all the beam specimens were sanded down to reveal fissures in the surface, if any. A series of flexural strength tests have been conducted on these specimens of concrete to determine the maximum internal stress a beam can withstand before breaking. Beams were subjected to a two-point loading configuration as per the specifications of IS-516:1959. The schematic diagram of the apparatus and loading scenario has been shown in Figure 6.




a) Flexural Strength Testing Machine




b) Flexural Testing

**Fig.6.** Schematic representation of flexural strength test and testing equipment

The Flexural Strength or modulus of rupture ($f_b$) is calculated as

$$f_b = \frac{3Pa}{BD^2} \tag{1}$$

for $a > 11$cm and $a < 13.3$ cm for 10 cm specimen, and,

$$f_b = \frac{PL}{BD^2} \tag{2}$$

for a >13.3 cm for 10 cm specimen. Where $a$ = Distance between line of fracture and nearer support, measured on the center line of tensile side of the specimen, $P$ = Maximum load (KN), $L$ = Support length (mm), $B$ = Width of specimen (mm), and $D$= Depth of Specimen (mm).

The beams were tested in the flexural strength testing machine. The sample and analysis plan has been presented in Table 5.

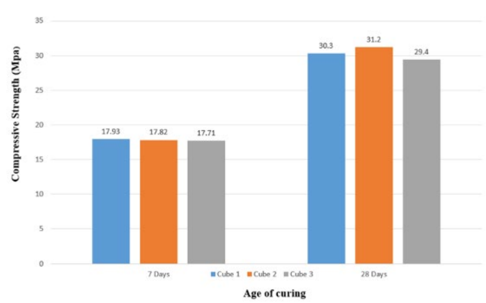
**Table 5.** Sampling and Analysis Plan for Flexural Strength Test

| Specimen type | No. of beams | |
|---|---|---|
| | PCC | RCC |
| M20 | 12 | 24 |
| M60 | 12 | 24 |

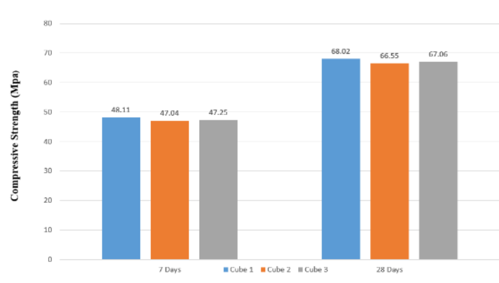
## RESULTS AND DISCUSSION

### Compressive Strength of Concrete

A total of 12 cubes were tested for M20 and M60 grade concrete mix as per sampling and analysis plan presented in Table 4. The results of the test have been presented in Figure 7a and 7b.




a) Compressive strength of M20 concrete




b) Compressive Strength of M60 Concrete

**Fig.7.** Results of Compressive Strength Test

For M20 concrete mix, the 7-days and 28-days average compressive strength were observed to be 17.82 N/mm$^2$ and 30.3 N/mm$^2$ respectively.

For M60 concrete mix, the 7-days and 28-days average compressive strength were observed to be 47.47 N/mm$^2$ and 67.21 N/mm$^2$ respectively.

### Flexural Strength of Concrete

#### *Flexural Strength of 360°-wrapped PCC Beams*

A series of flexural strength test have been carried out on PCC beam specimens strengthened with 360°-wrapping technique. The results of the tests have been presented in Table 6. For both M20 and M60 grade PCC Beams, it has been observed that flexural strength increases with increase in number of SSWM layers. Flexural strength ranges from 3.17 to 3.76 N/mm$^2$ and 5.54 to 6.6 N/mm$^2$ for M20 and M60 grade specimens respectively. Flexural strength increased from 6% to 18% for M20 grade beam specimens and 8% to 19% for M60 grade specimens with increase in number of layers in comparison to the control beam.

**Table 6.** Results of Flexural Strength Tests on PCC Beams Strengthened with 360°-wrapping technique

| No of Layers | M20 | | M60 | |
|---|---|---|---|---|
| | Peak load (KN) | Flexural Strength (N/mm$^2$) | Peak load (KN) | Flexural Strength (N/mm$^2$) |
| Control Beam | 8 | 3.17 | 13.8 | 5.54 |
| Single Layer | 8.5 | 3.36 | 15.1 | 6.0 |
| Two Layers | 8.9 | 3.56 | 16.0 | 6.4 |
| Three Layers | 9.4 | 3.76 | 16.6 | 6.6 |

#### *Flexural Strength of U-wrapped RCC Beams*

A series of flexural strength test have been carried out on RCC beam specimens strengthened with U-wrapping technique. The results of the tests have been presented in Table 7. For both M20 and M60 grade RCC Beams, it has been observed that flexural strength increases with increase in number of U-wrapped SSWM layers. Flexural strength ranges from 8.40 to 9.57 N/mm$^2$ and 12.23 to 13.70 N/mm$^2$ for M20 and M60 grade specimens respectively. Flexural strength increased from 6% to 14% for M20 grade beam specimens and 4% to 12% for M60

grade specimens with increase in number of U-wrapped layers in comparison to the control beam.

**Table 7.** Results of Flexural Strength Tests on RCC Beams Strengthened with U-wrapping technique

| No of Layers | M20 | | M60 | |
|---|---|---|---|---|
| | Peak load (KN) | Flexural Strength ($N/mm^2$) | Peak load (KN) | Flexural Strength ($N/mm^2$) |
| Control Beam | 21 | 8.40 | 30.2 | 12.23 |
| Single Layer | 22.4 | 8.90 | 31.8 | 12.70 |
| Two Layers | 23.2 | 9.24 | 32.8 | 13.08 |
| Three Layers | 24 | 9.57 | 34.8 | 13.70 |

***Flexural Strength of 360°-wrapped RCC Beams***

A series of flexural strength test have been carried out on RCC beam specimens strengthened with 360°-wrapping technique. The results of the tests have been presented in Table 8. For both M20 and M60 grade RCC Beams, it has been observed that flexural strength increases with increase in number of 360°-wrapped SSWM layers. Flexural strength ranges from 8.40 to 10.17 $N/mm^2$ and 12.23 to 14.00 $N/mm^2$ for M20 and M60 grade specimens respectively. Flexural strength increased from 8% to 22% for M20 grade beam specimens and 7% to 15% for M60 grade specimens with increase in number of 360°-wrapped layers in comparison to the control beam.

**Table 8.** Results of Flexural Strength Tests on RCC Beams Strengthened with 360°-wrapping technique

| No of Layers | M20 | | M60 | |
|---|---|---|---|---|
| | Peak load (KN) | Flexural Strength ($N/mm^2$) | Peak load (KN) | Flexural Strength ($N/mm^2$) |
| Control Beam | 21 | 8.40 | 30.2 | 12.23 |
| Single Layer | 22.9 | 9.01 | 32.8 | 13.08 |
| Two Layers | 24.2 | 9.66 | 34.3 | 13.71 |
| Three Layers | 25.9 | 10.17 | 35.0 | 14.00 |

Similar results have been observed by Qeshta *et al.* 2015, Rahulreddy (2017), Sowmya and Venkatasubramani (2017), Jagadeesan *et al.* 2020.

## LIMITATIONS OF THE STUDY

The study has the following limitations:

- Due to time and resource constraints, the effect of U-wrap strengthening has not been explored for PCC Beams.
- The effect of increase in thickness of SSWM is not investigated.
- Finite element analysis-based software can also be carried out to test various combinations concrete grade, wrapping methods, thickness of SSWM and age of concrete.

## CONCLUSION

Based on the results and discussions, following conclusions have been drawn:

- A significant improvement in flexural strength of SSWM wrapped specimens has been observed in comparison to the un-wrapped specimens.
- The M20 and M60 grade concrete beam specimens U-wrapped with 3-layer SSWM showed higher flexural strength gain.
- Similar trend has been observed for 3-layer 360°-wrapping of M20 and M60 Beam Specimen.
- Higher strength gain has been observed for M20 grade concrete beams in comparison to M60 grade concrete beams.
- Both 360°-wrapping and U-wrapping techniques can significantly enhance the strength of structures.
- Further research is required to see the effect of wrappings on flexural strength of old beams/ columns. This should be done through FEM based software and then, should further be validated through experimental analysis.

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